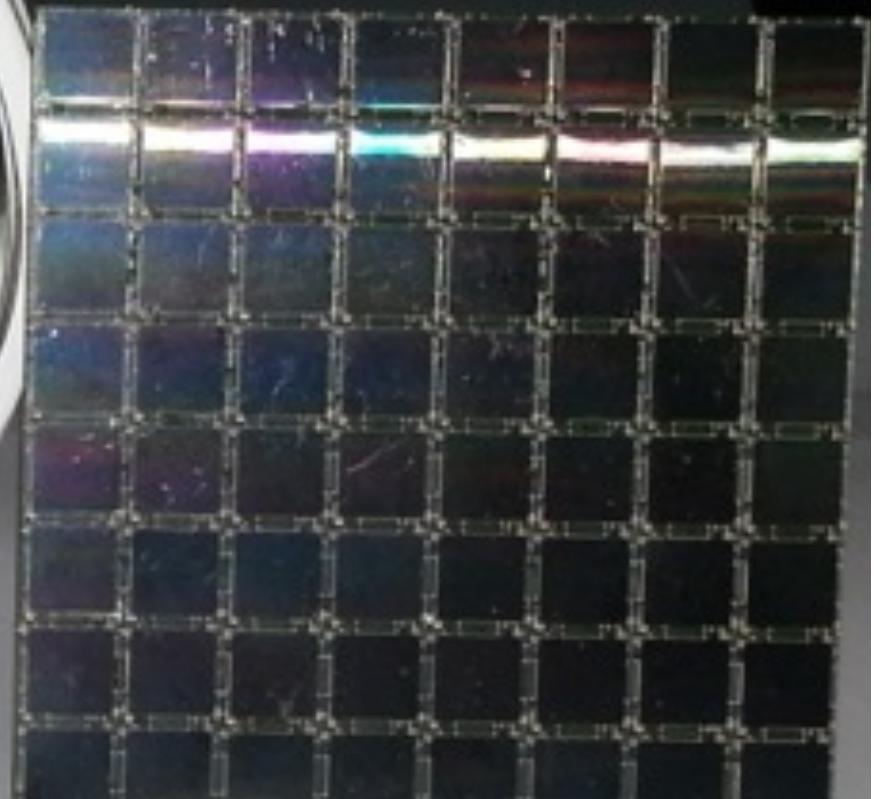


Strategy gives you directions.
Technology leads the way.



SiPM for DarkSide-20k

on behalf of the DarkSide-20k collaboration

Biagio Rossi

Princeton University/INFN Napoli
Dark Matter 2016
UCLA, Los Angeles, USA
Feb 19th, 2016

rossib@princeton.edu

DarkSide-50

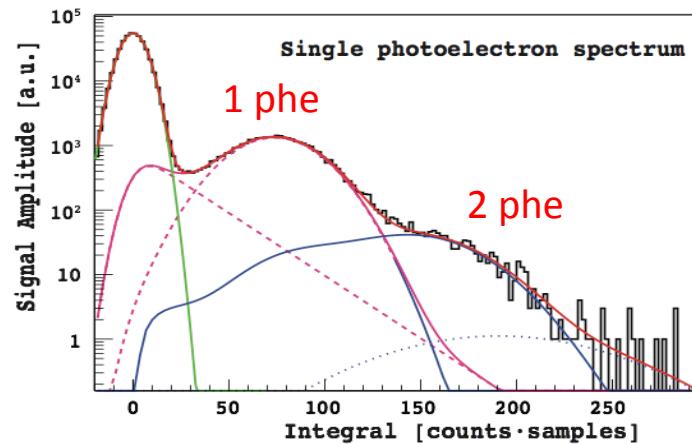


- 50 kg active mass
- Φ 36 cm x 36 cm
- 19 (top) +19 (bottom) R11065
Hamamatsu 3inch PMTs

PMT misbehave at LAr temperature

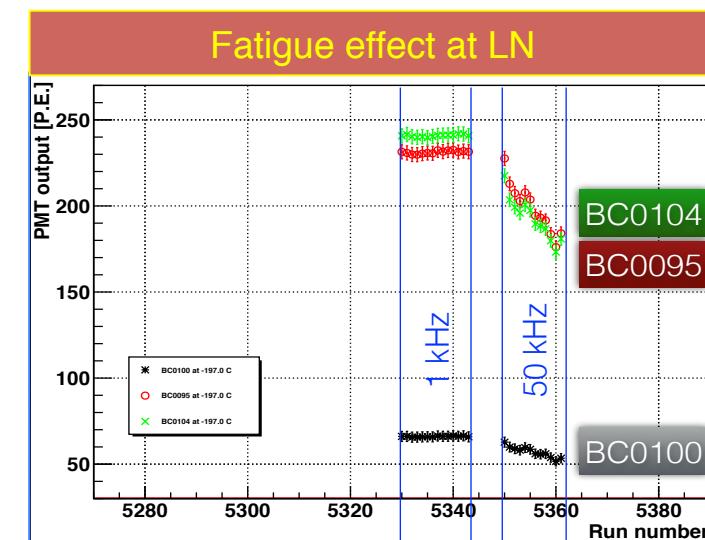
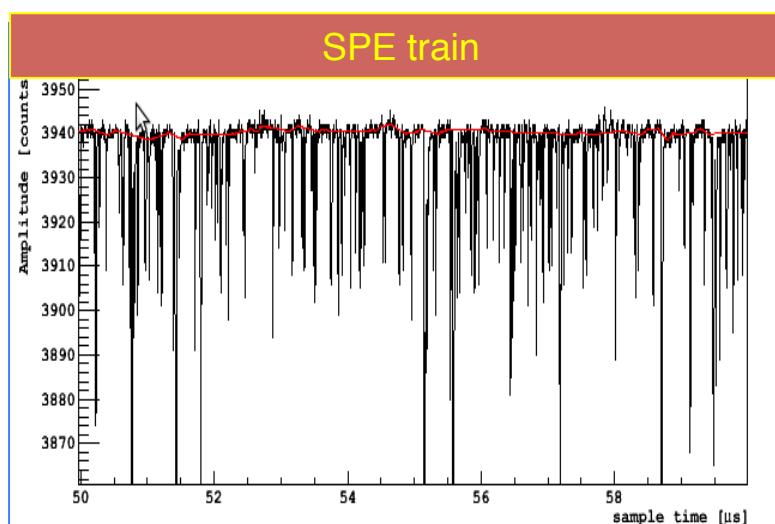


DarkSide-50 Cryogenic PMTs



PRO/CONS

- High quantum efficiency (QE=35%)
- Afterpulsing rate <1-2%
- Darkrate < 500 Hz
- Very expensive
- SPE train when gain >10⁶ forced to develop cold amp
- Long gain stabilization, Slow turn-on, Fatigue, Hysteresis, etc.

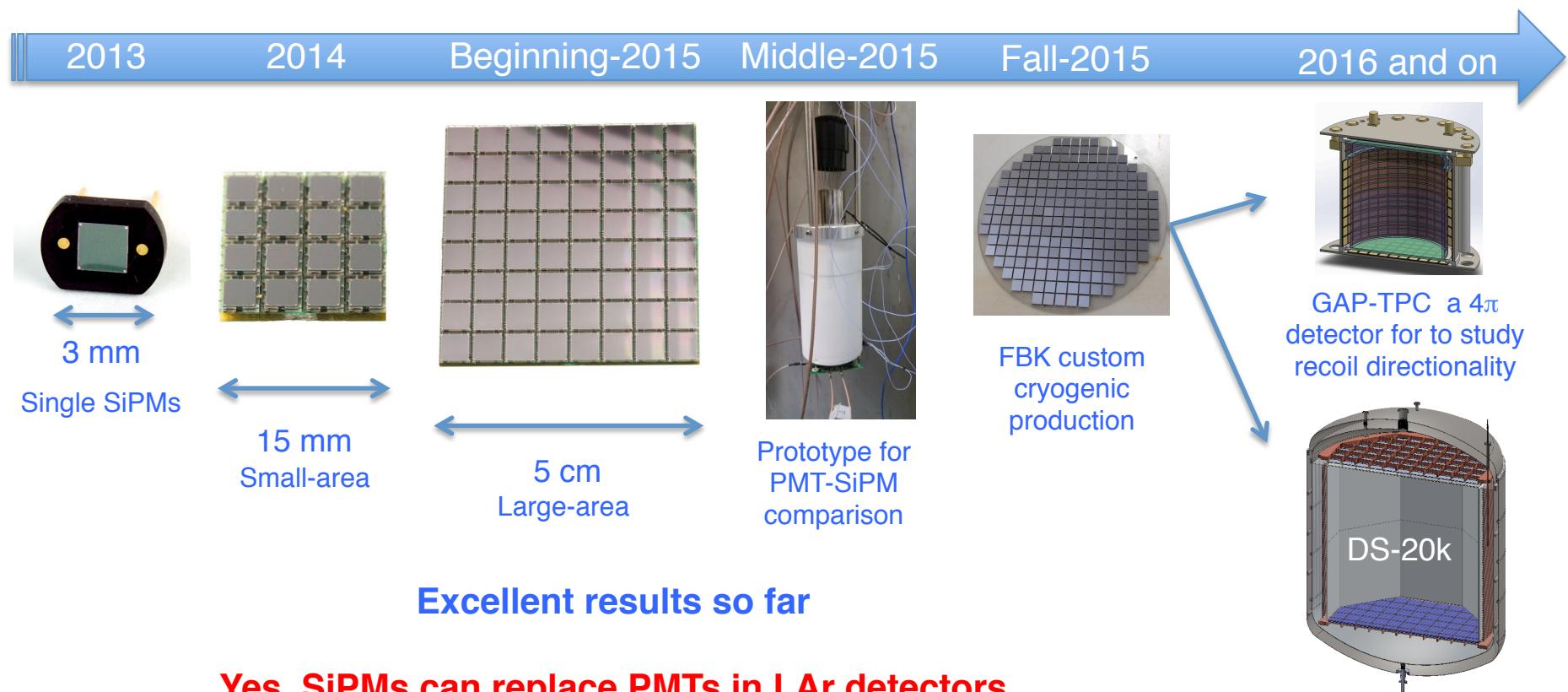


Not a suitable solution for a large-size LAr DM detector

Are SiPMs a valuable alternative ?

In the fall of 2013 we started a path to assess the feasibility of using SiPMs in a LAr detector

1. Testing commercial SiPMs performance at LAr temperature
2. Develop cryogenic read-out electronics for reducing the number of channel outputs



SiPM vs PMTs

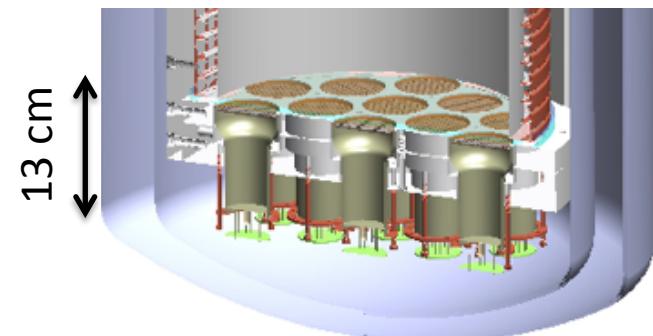
PROs

- Low operation voltage (20-30V)
- Increase photocathodic coverage of the TPC and in principle allow for 4pi coverage
- Compactness (width <1 cm) -> increase the ratio active/total target volume
- Price
- Customizable size and performance
- Excellent photon counting capabilities and SPE resolution
- Readout pattern can be chosen at convenience -> Improve XY resolution on the edge of the TPC for surface background rejection
- Very high PDE>50% (increasing year-by-year)
- Virtually radioactive-free (Silicon is very radiopure material BUT materials used in the substrate or package of the chip can be radioactive)

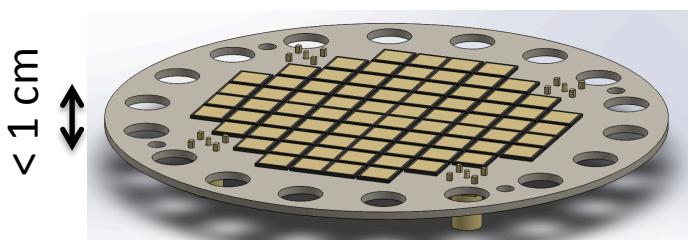
CONS

- Dark rate
- Correlated pulses
- Recovery time (pulse width)
- Cryogenic readout needed

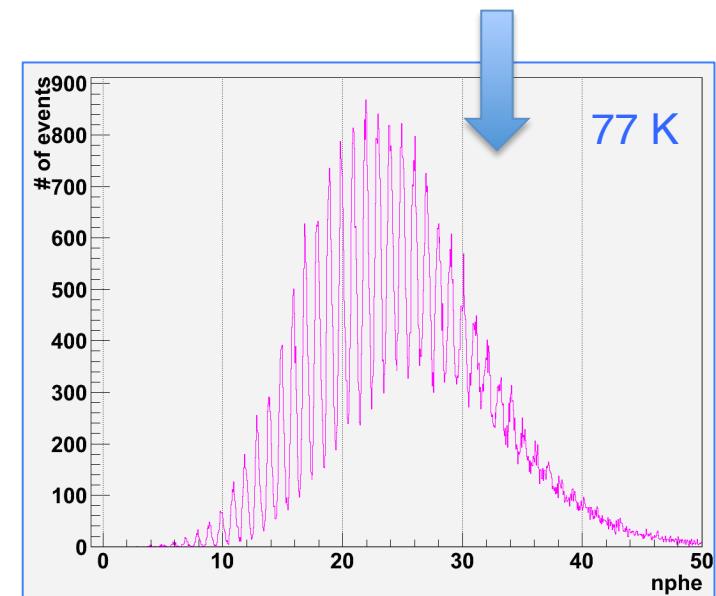
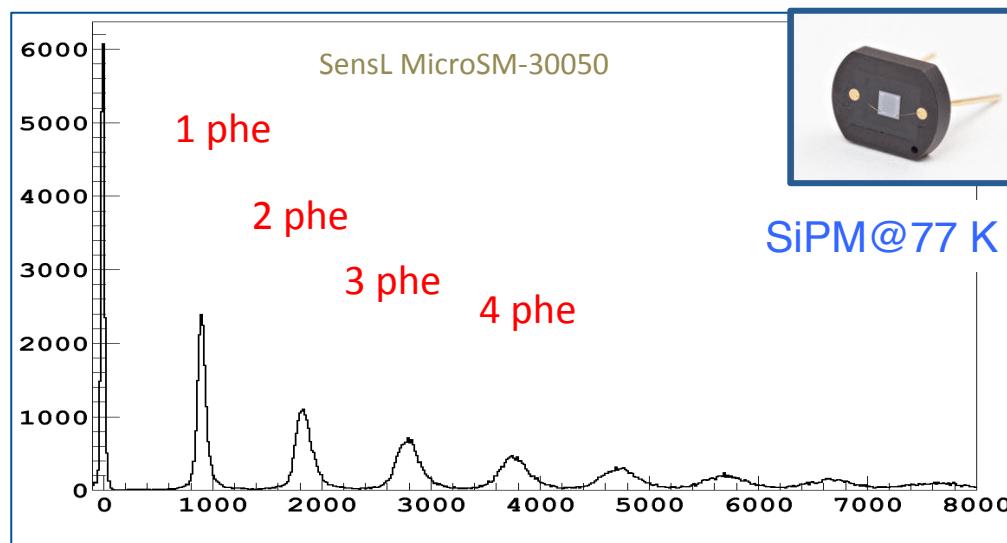
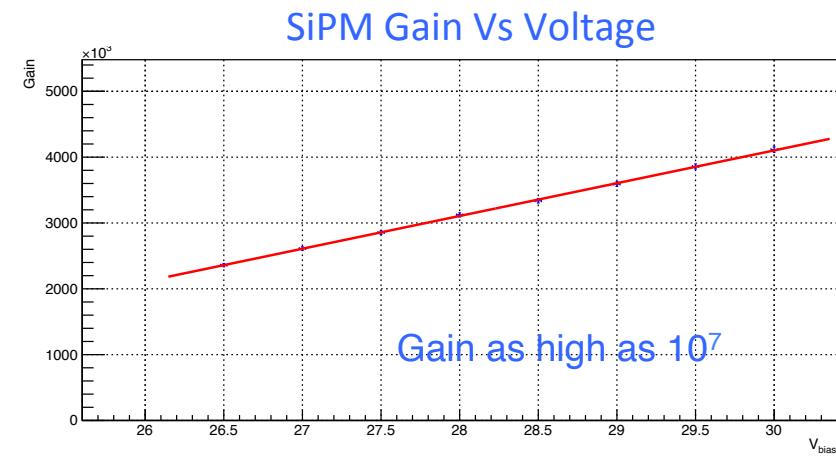
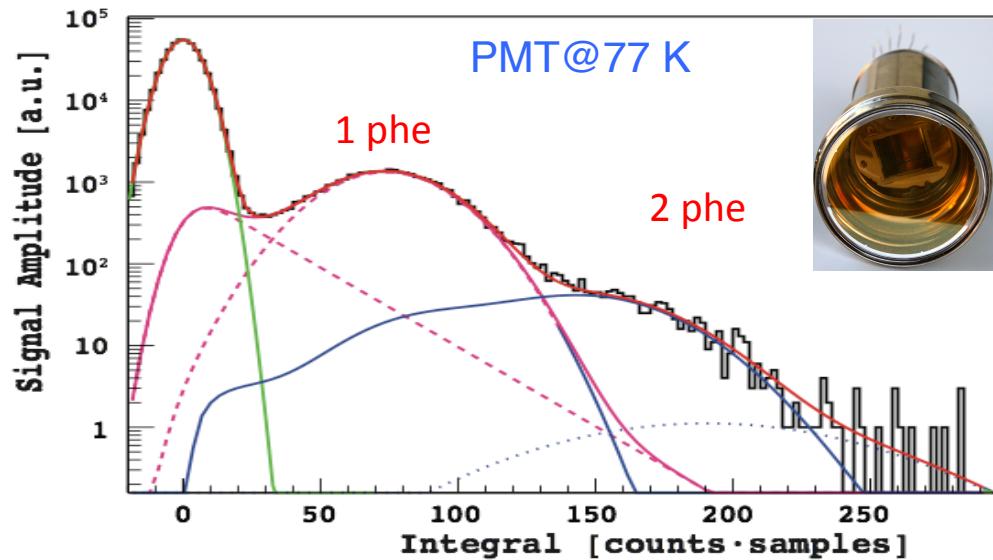
PMT LAr-TPCs



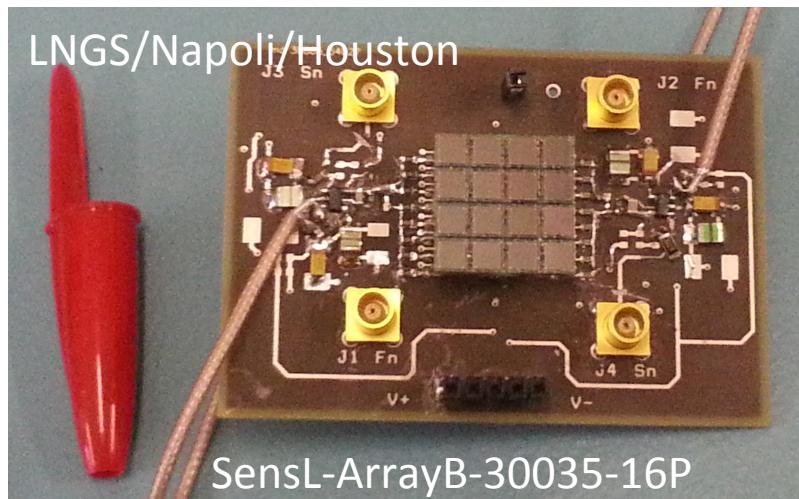
SiPM LAr-TPC



SiPM performance at LAr: excellent photon counting capabilities

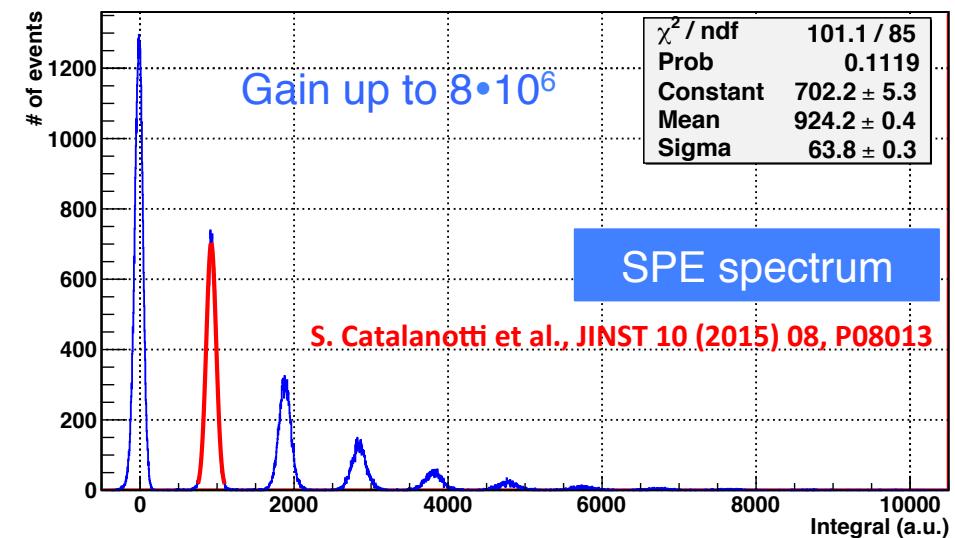
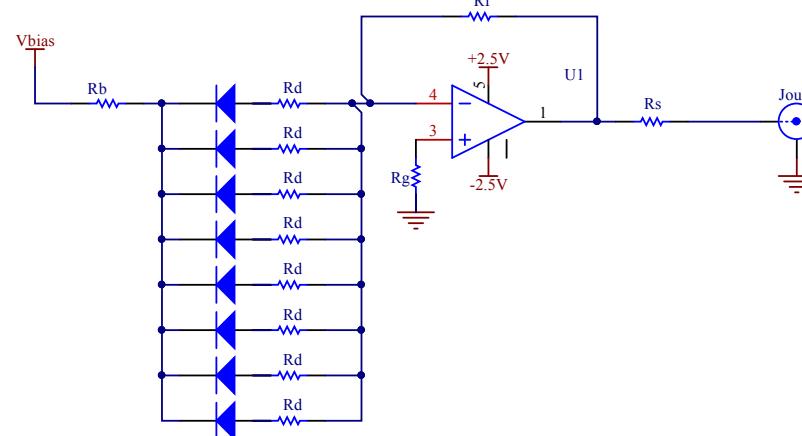


A small-size commercial array (2014)



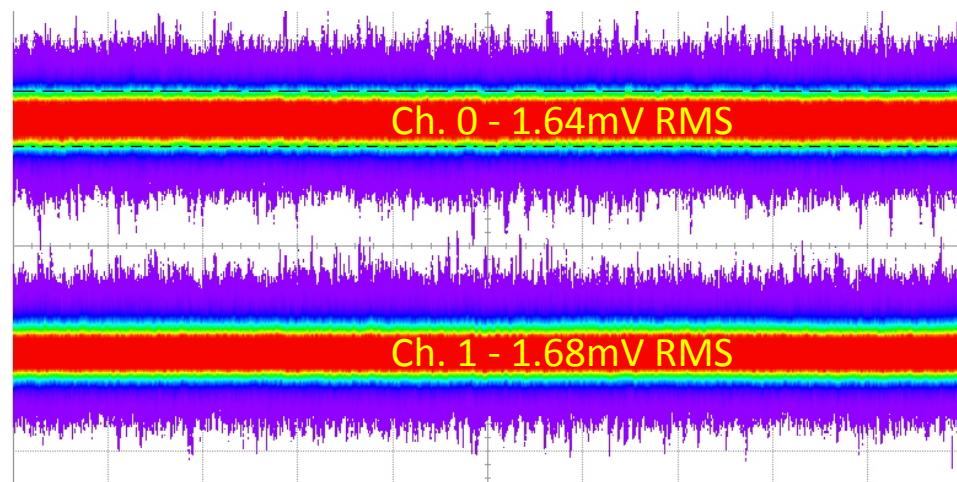
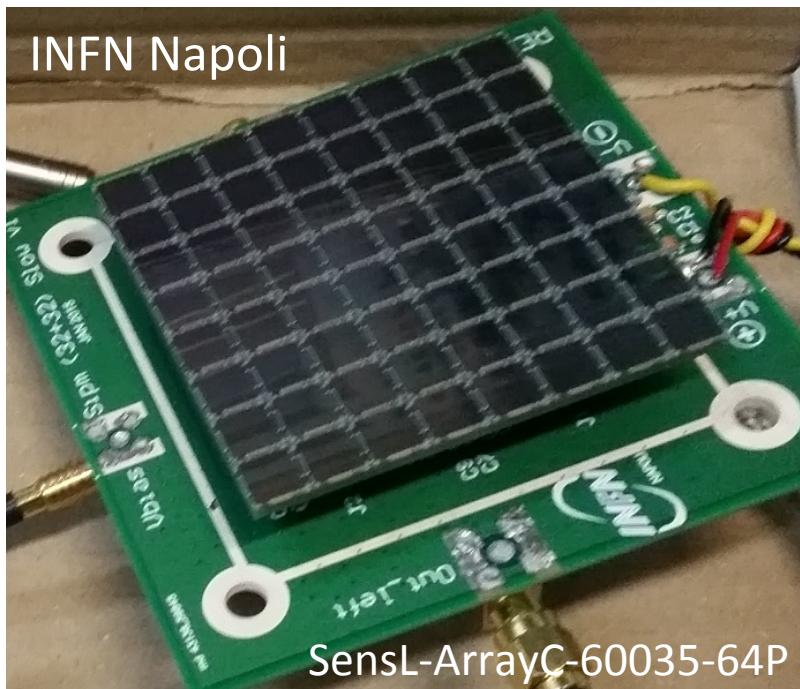
- Array size: 1.5x1.5 cm² (total 225 mm² - active 144 mm²)
- 64 SiPMs of 3x3 mm²
- SPAD size 35 μm
- SPAD capacitance ≈150 fF (@RT)
- SiPM PDE: 41% (@5V_{ov})
- SiPM Capacitance 0.85 nF/channel
- Array fill factor about 65%
- Cryogenic readout board with 2 outputs 8 channels summed each
- Power consumption 120mW

Active sum (trans-imp amplifier)



ROBUSTNESS: THE ARRAY SURVIVED MANY COOLING CYCLES

A large-size commercial array (2015)



Electronic noise $\text{RMS} \approx 1.5 \text{ mV}$
Cryogenic amplifier very stable

- Array size: $5 \times 5 \text{ cm}^2$ (active 2304 mm^2)
- 64 SiPMs of $6 \times 6 \text{ mm}^2$
- SPAD size $35 \mu\text{m}$
- SPAD capacitance $\approx 150 \text{ fF}$ (@RT)
- Nominal SiPM PDE: 41% (@ $5V_{ov}$)
- SiPM Capacitance $3n\text{F}/\text{channel}$
- Array fill factor about 76%
- Cryogenic readout board with 2 outputs 32 channels summed each

Main issues to face:

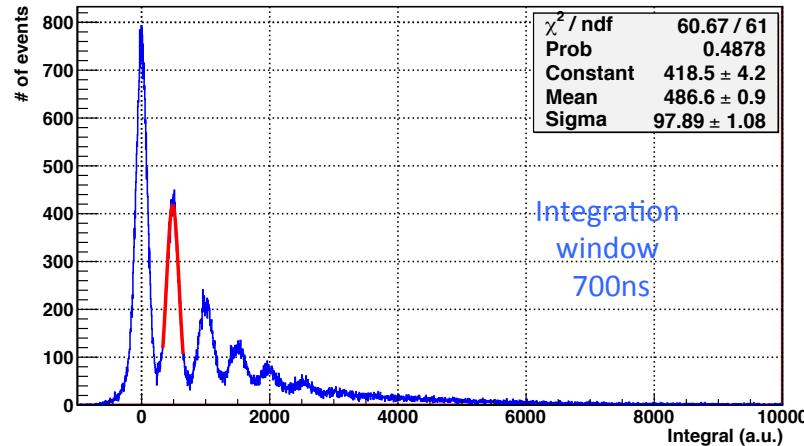
1. Keep low power consumption (40 mW)
2. Prevent bubbling (heat hot spots)
3. SiPMs have huge capacitance nF/cm^2
4. Large input capacitance reduce the BW
5. Large input capacitance increase noise



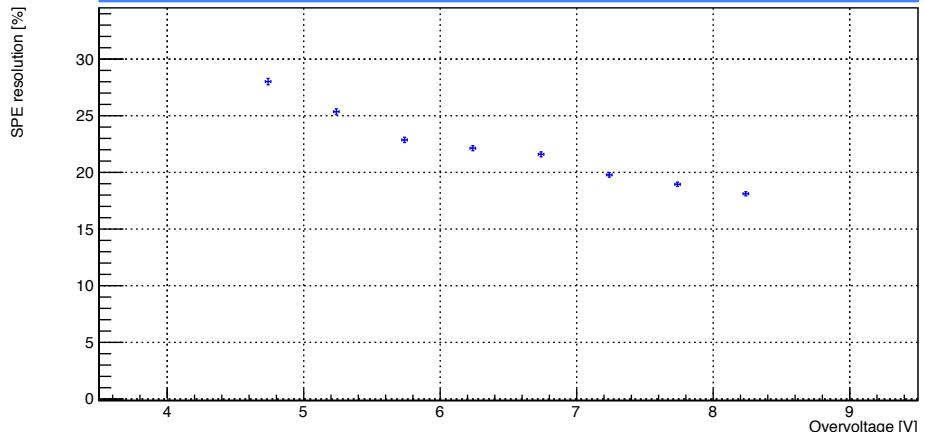
One cannot sum up a very large number of SiPM

SensL ArrayC-60035-64P performance at LAr

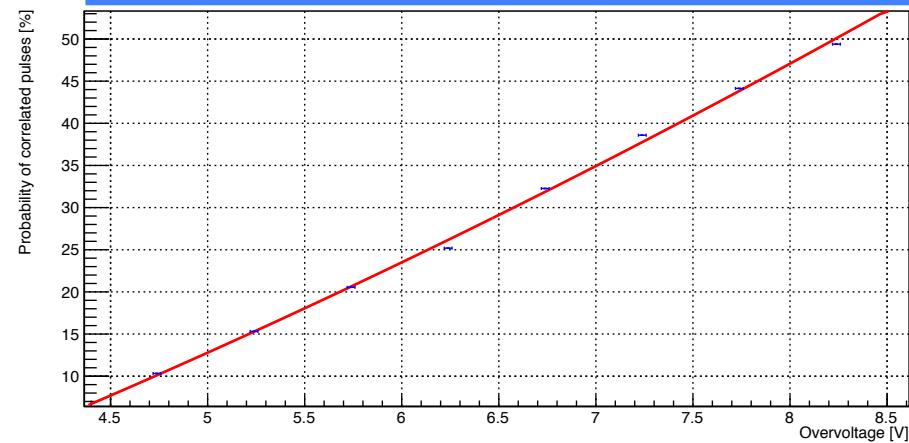
Single Photoelectron spectrum



SPE resolution vs V_{ov}



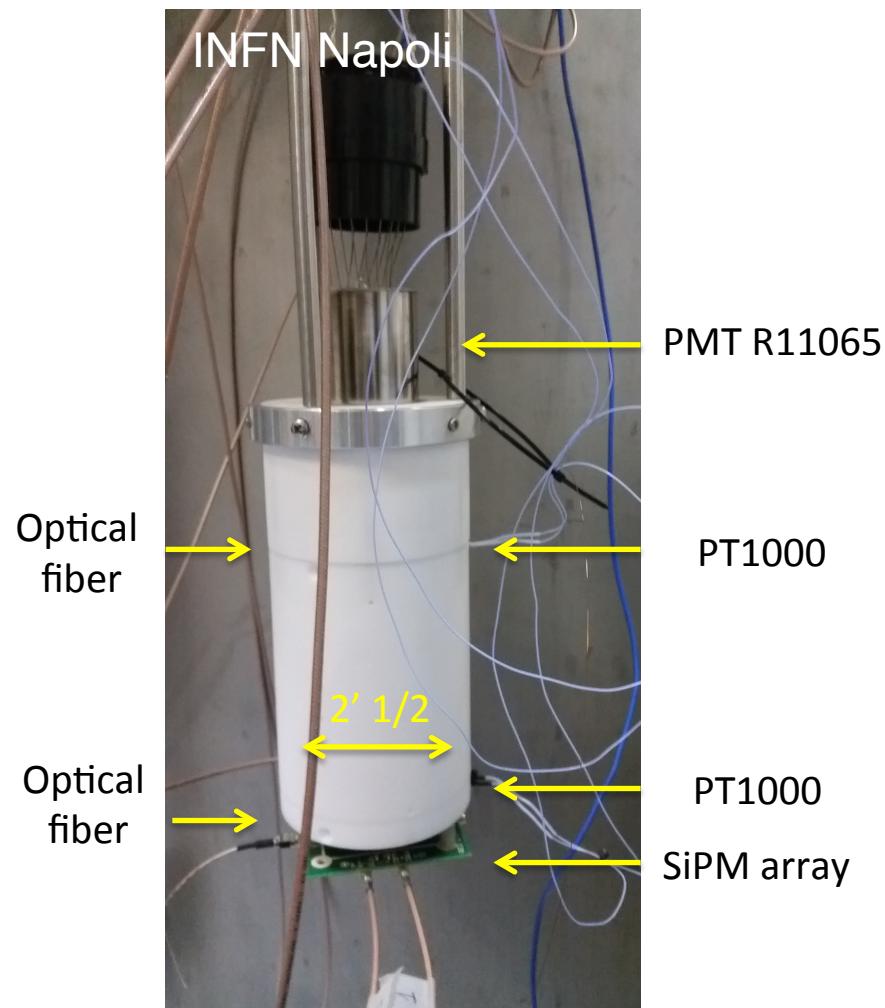
Probability of correlated pulses vs V_{ov}



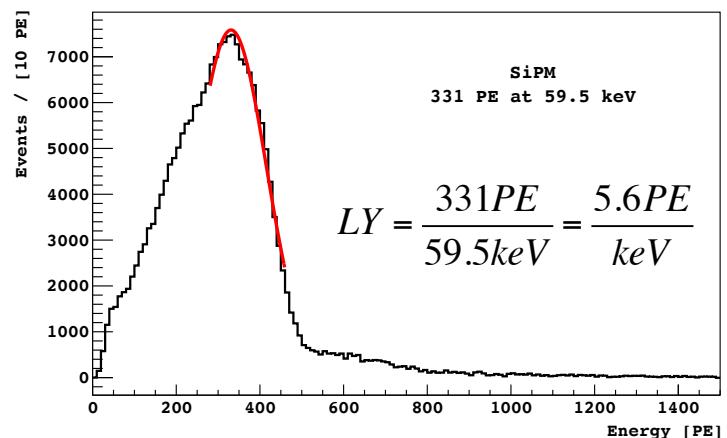
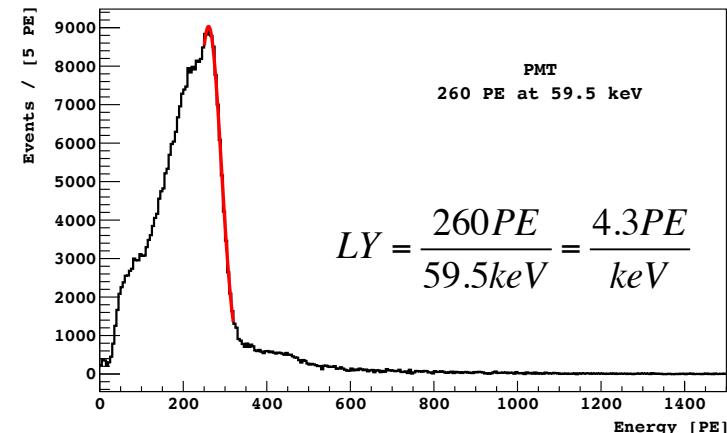
Commercial arrays are
not radioclean

SiPM usually installed on
a PCB board

SiPM vs PMT in LAr



B. Rossi et al. JINST 11 (2016) 02, C02041



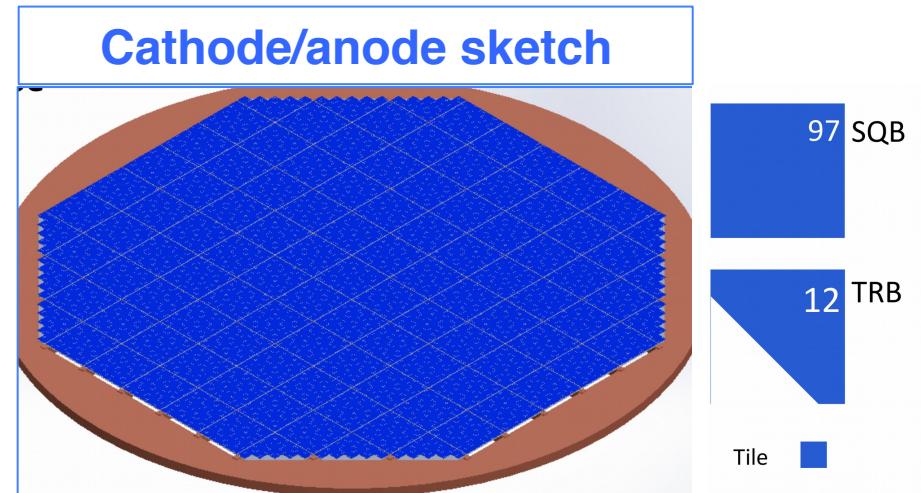
Record total LY collected of
9.9 PE/keV

SiPM “sees” 20% more light than the PMT

DS-20k strategy on photosensors

Plan for 5000 photodetectors

- 5x5cm² radiopure tiles (3" PMT equivalent)
- 97 squared 25x25cm² motherboards arrays (2450)
- 12 triangular motherboards array (180 tiles)
- About 5000 tiles to cover DS-20k's anode and cathode with maximum photocathodic coverage



See J. Martoff talk

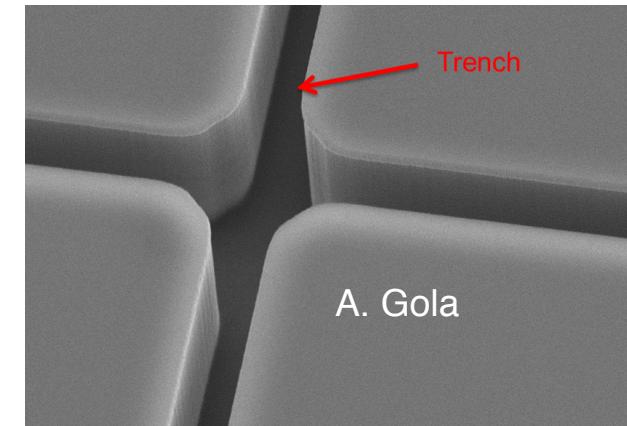
A full chain (development-production-packaging-testing) strategy

1. Custom SiPM development (FBK) for cryogenic temperature and large-scale production (LFoundry)
2. Multiple SiPM test stations to feedback and guide the development phase
3. Radiopure and robust packaging of the tiles
4. Radiopure cryogenic readout board to reduce output channels
5. Integration of the photosensor with the readout board
6. Massive test characterization and selection of detector modules before the installation in DS-20k TPC

SiPM requirements for DS-20k

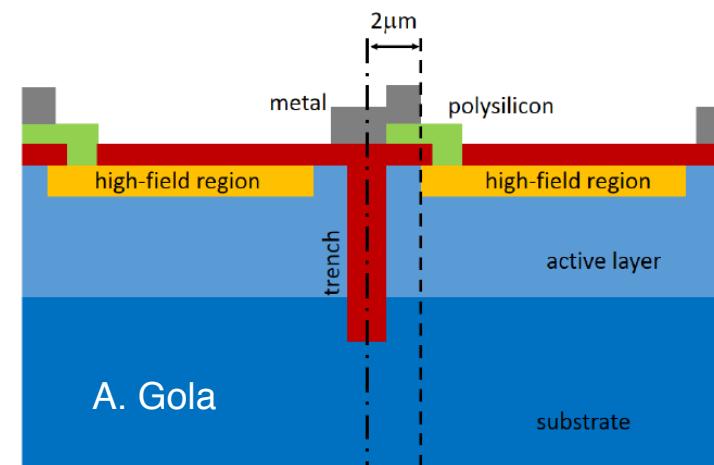
DS-20k collaboration initiated a custom R&D on SiPM with FBK

1. PDE larger than **40%** at 420 nm
2. Dark count rate (DCR) lower than **0.1 Hz/mm²**
3. Total correlated noise probability (TCNP) (crosstalk + afterpulsing) lower than **40 %**
4. Photo-electron gain larger than **1M**
5. Signal duration of less than **300 ns**



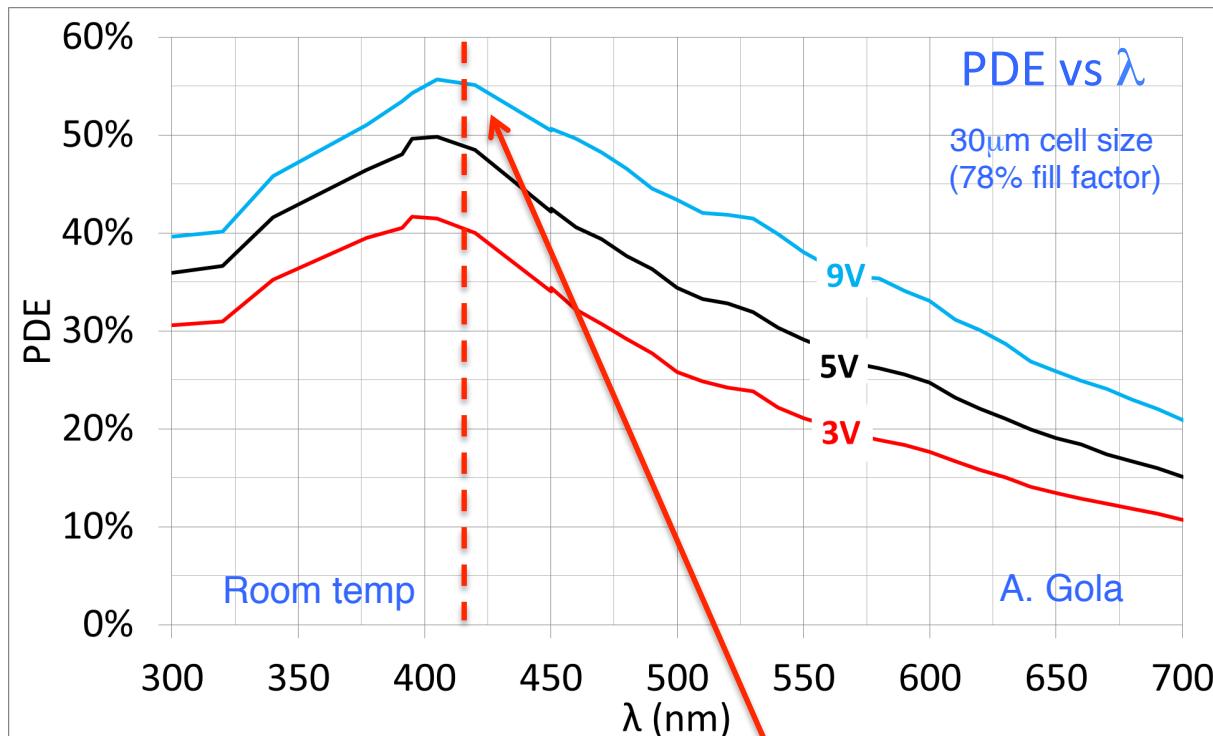
FBK recently developed HD technology that has a narrow border region around each SPAD to increase PDE (QE) and a trench system to reduce the optical cross talk

The HD technology introduced by FBK
meets and beats all the requirements

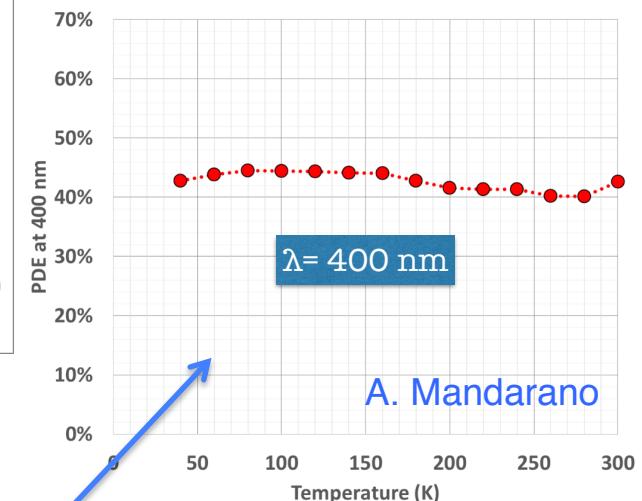


FBK NUV-HD technology performance: PDE

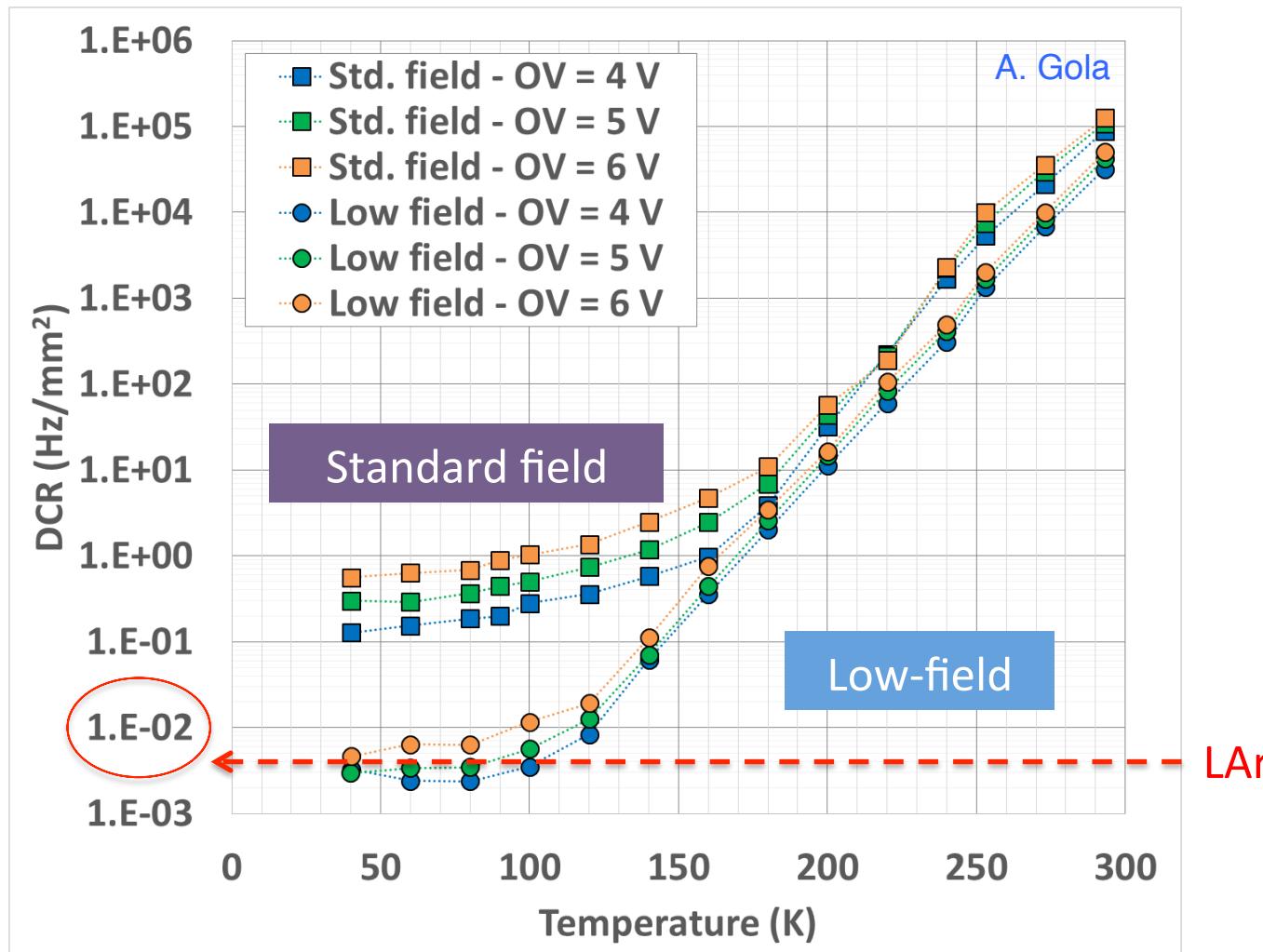
First custom production shows very encouraging performance



PDE as high as 55% for large OverVoltage
And it stays constant as a function of the temperature



FBK NUV-HD technology performance: Dark Rate

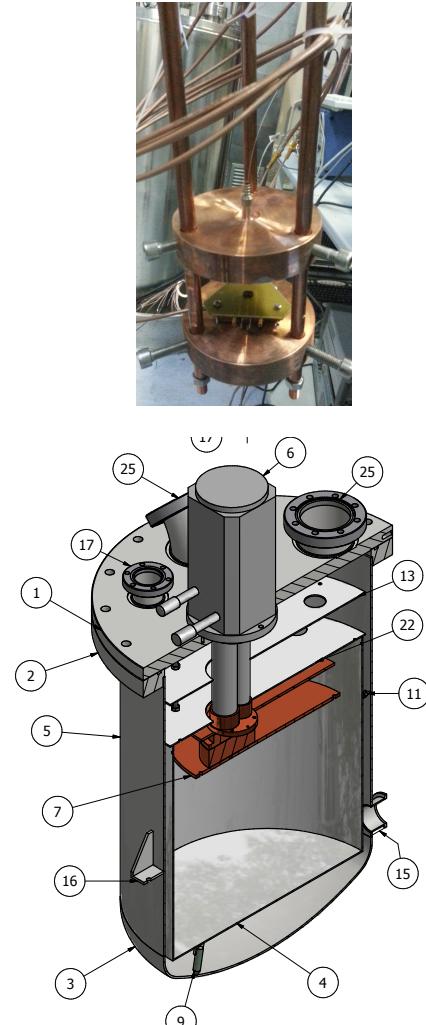


About **10⁷** reduction in DR reduction from Room temperature to LAr

A 50x50 mm² SiPM array would have a total **DCR < 30 Hz!**

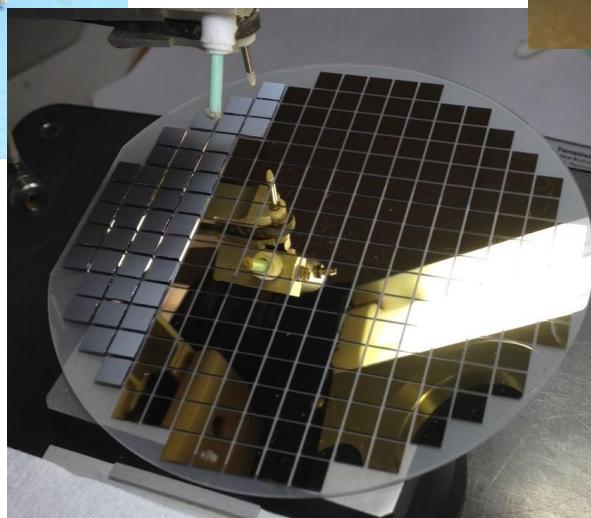
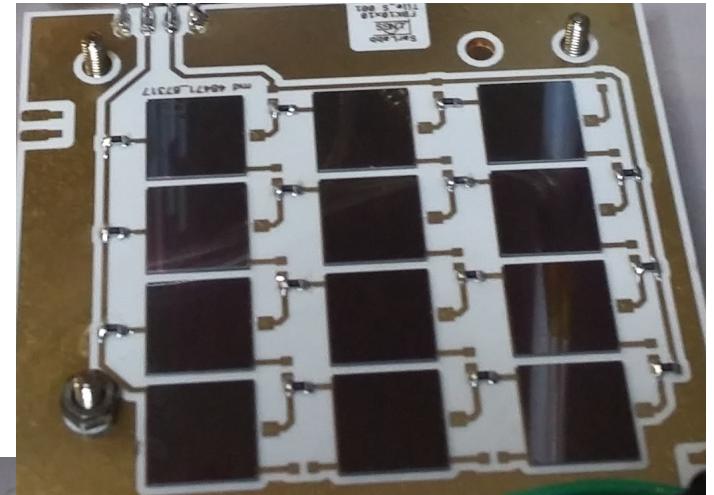
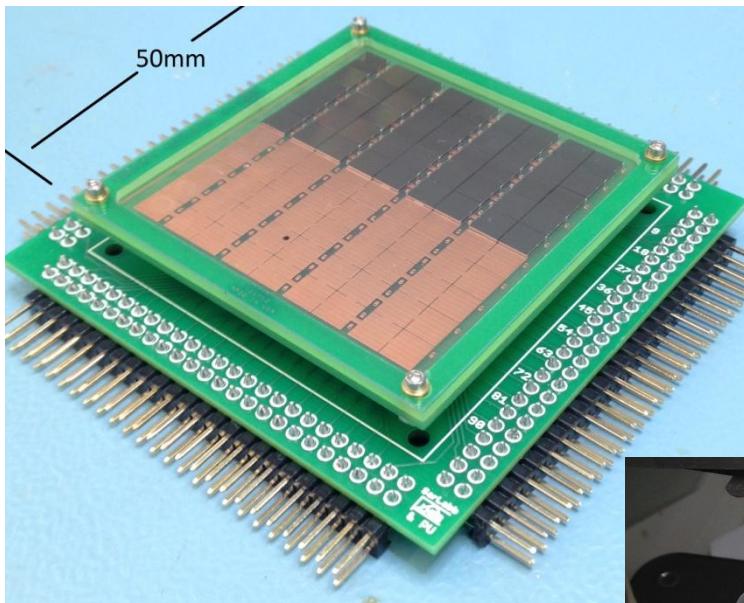
DS-20k SiPM test stations

Multiple test stations to feedback and guide the development phase at LNGS and INFN Napoli (50-100 SiPMs tested per week capable)



Packaging

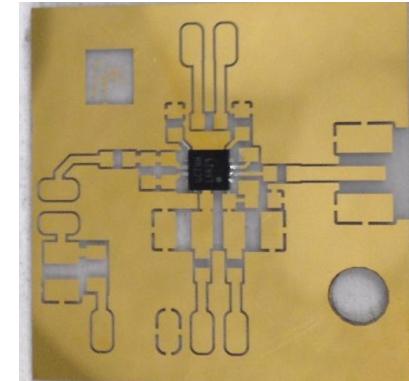
Research and development of assemblies on radio clean substrates at Princeton



Radio pure readout cryo-electronics

Accomplishments

- Performance of the cryo-readout board are already quite satisfactory
- Total power <200mW per DM
- Reduction of the radioactive budget of the readout board by using fused silica substrates

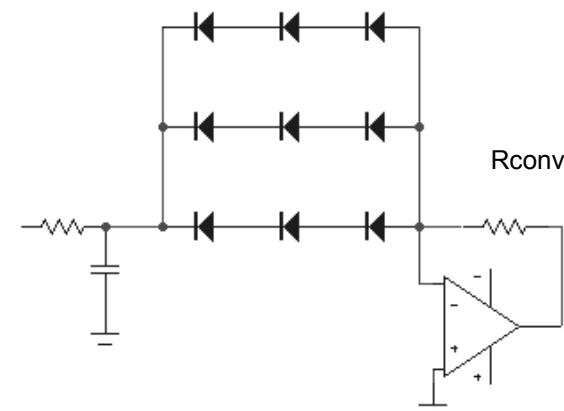


NEXT STEPs

- Introduce on SiPM-chip TSV packaging

OPTIONAL

- Make use of deposited film resistor and silicon base capacitors
- A slight different readout approach (series/parallel) is under investigation to try to enhance the readout board performance.



Massive test of all Detector Modules

All the 5000 photodetector modules will be cryo-tested before the installation



INFN Napoli Existing infrastructures:

- 70m² clean room
- 250 lt cryostat already equipped for testing 25 DMC contemporary
- DAQ system up to 32 channels
- Bias Voltage mainframe
- Pumping system + leak checker
- 50 lt ultrasonic bath
- Optical system (laser+splitter)
- Monochromator (UV)
- PT60 and Lakeshore
- LN external tank of 3000 liters with cryogenic lines

Summary

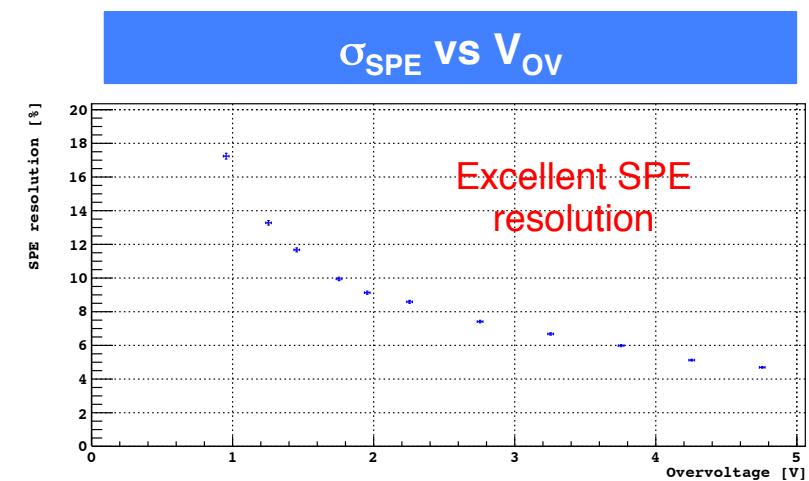
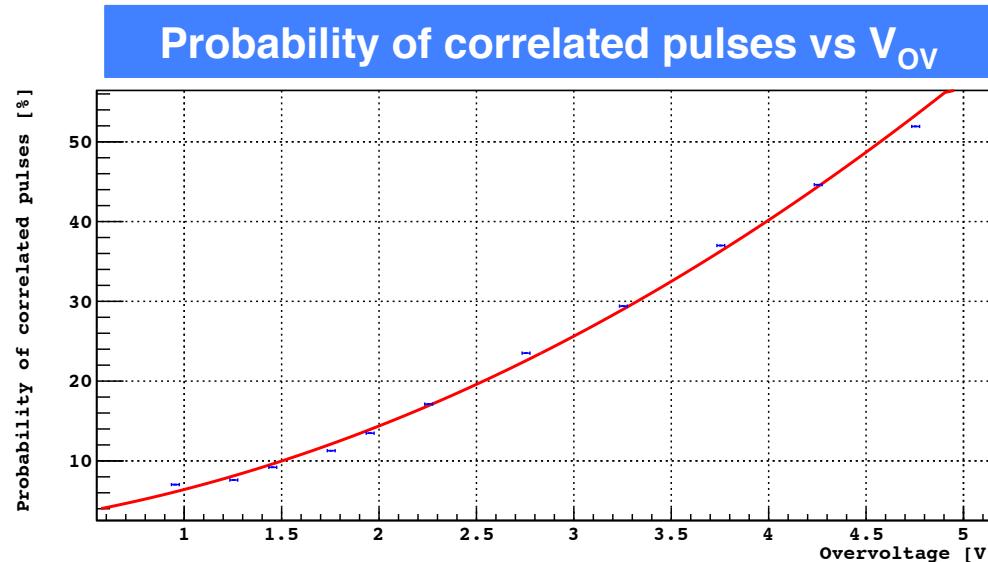
- In the last years an aggressive R&D path have been conducted to assess the feasibility of replacing PMTs with SiPMs
- Commercial SiPMs have shown great performance at the LAr temperature
- SiPM QE already higher than cryogenic Hamamatsu PMTs
- Custom cryogenics FBK production showed very promising performance (especially for QE and DR)
- The HD Technology introduced by FBK meets and beats all requirements for operations DarkSide-20k
- Strategy for massive production-packaging-test chain led by INFN

Napoli, Italy

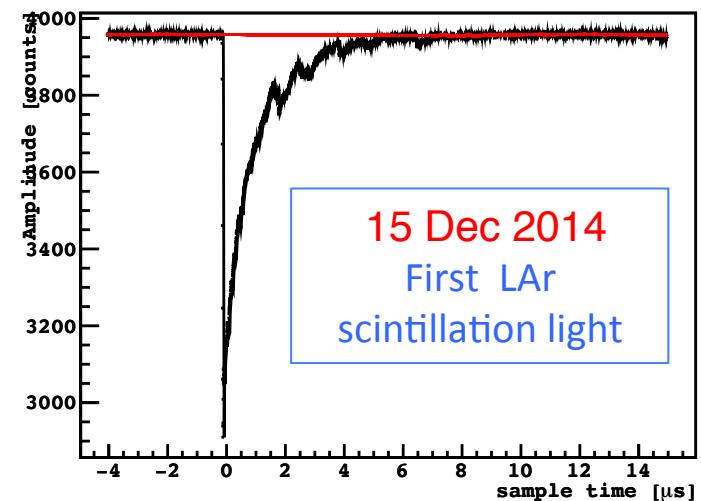
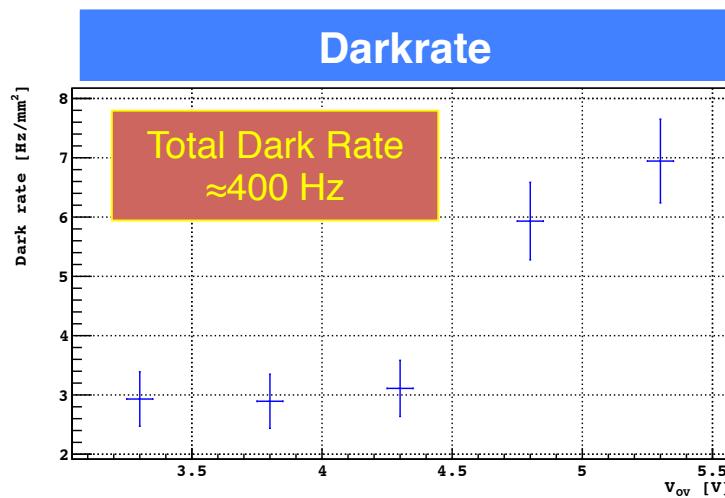


Thank you

SensL ArrayB-30035-16P: performance@LAr



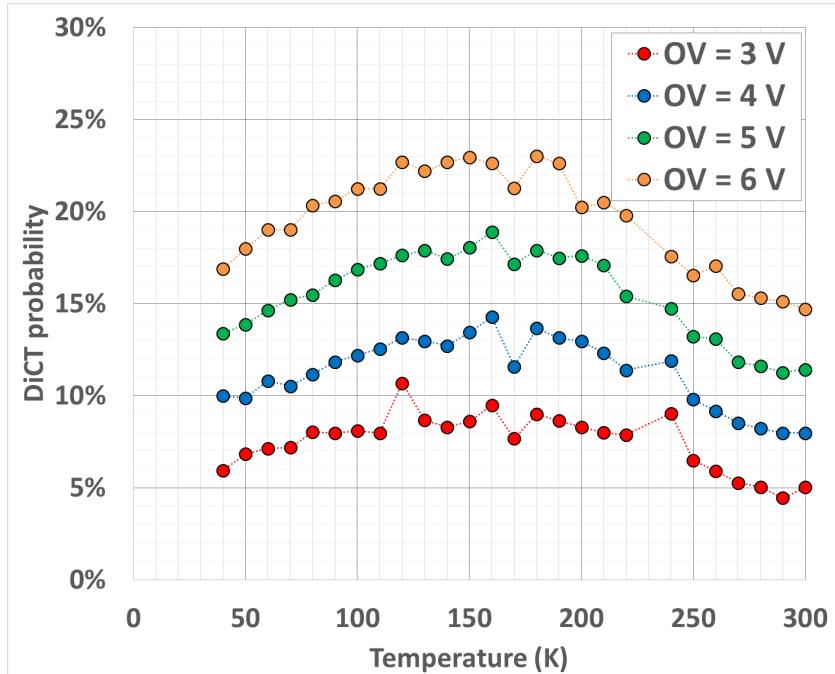
Cryo-readout board performs great
(signal-to-noise)



S. Catalanotti et al., JINST 10 (2015) 08, P08013

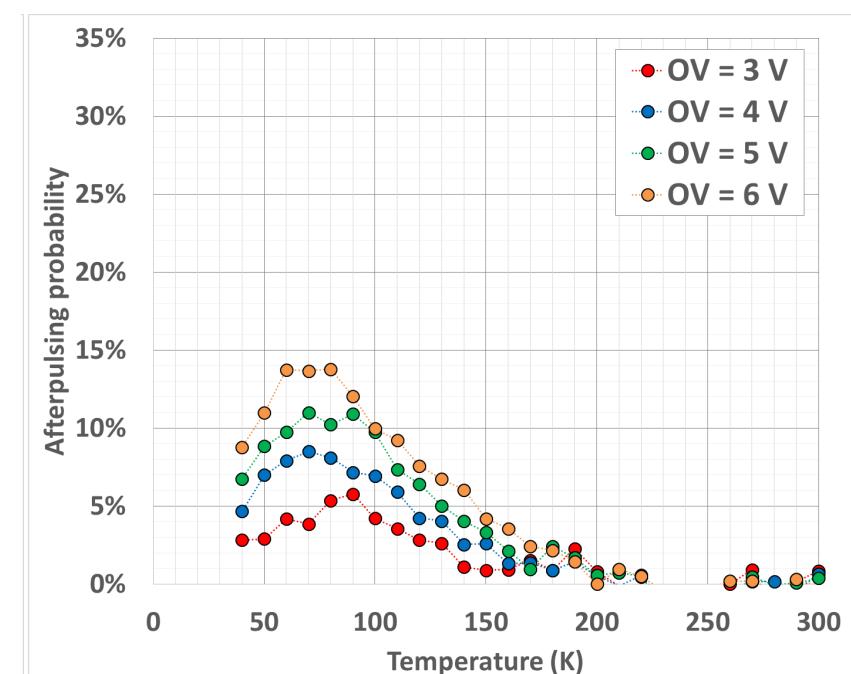
FBK NUV-HD technology performance: Correlated pulses

Optical cross talk Vs T



Low field

Afterpulses Vs T



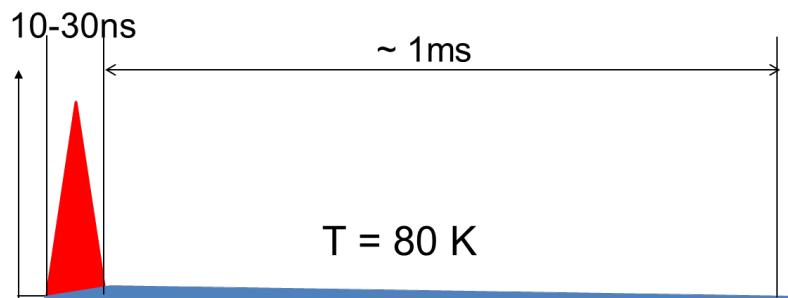
Low field

- Total correlated pulses 10%+10% (can be improved in next productions)
- Correlated pulses **not harmful** in DS-20k detector

Recharge time

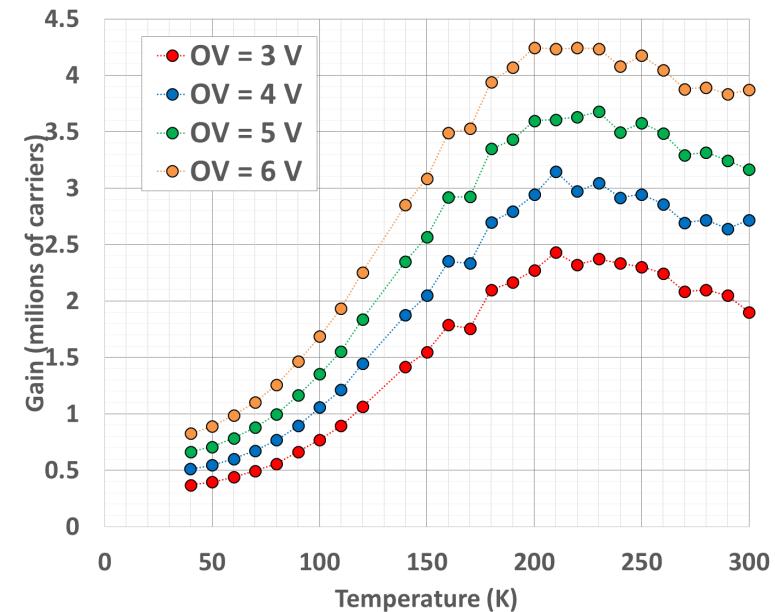
Benefits

- Short signal, composed only of the fast peak.
- Complete suppression of after-pulsing.
- Highest PDE, using larger cells \geq 30 μm at higher OV.
- Higher yield / better reproducibility at low T.



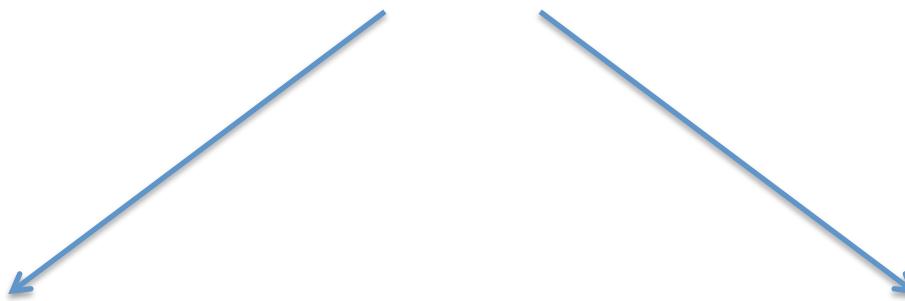
Drawbacks

- Reduced gain / signal amplitude for a given amplifier bandwidth.

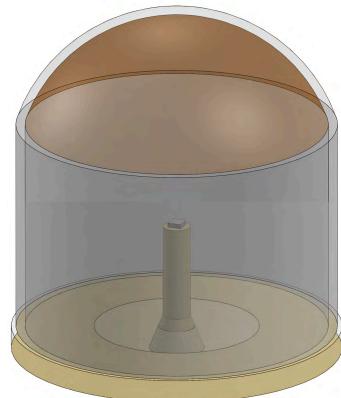


NUV-HD SiPM Gain
500 ns gate

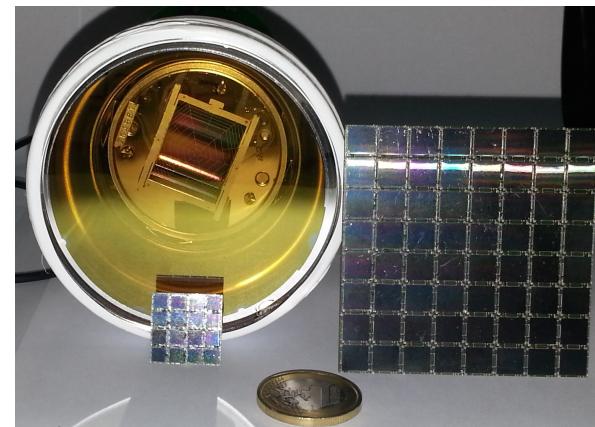
Can we use different (better) light sensors for LAr-TPCs ?



SiGHT
(H. Wang - UCLA)



SiPM technology



Detector module assembly

SiPM tiles will be assembled with front end electronics on a copper foil frame to convey the heat and possible bubbling away from HV cathode region

